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RESEARCH INSTITUTE

DETECTION OF VARIATIONS IN ASPEN FOREST HABITAT FROM LANDSAT DIGITAL DATA: BEAR RIVER RANGE, UTAH

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by

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ABSTRACT

The objective of this study is to utilize satellite data to serve the particular nformation needs of federal and state forest managers concerning the nature and extent of aspen resources in the Bear River Range, located in northeastern Utah. Such aspen habitat information is vital to the formulation of forest management plans which must consider aspen replacement by conifers as well as preserve the watershed cover, wildlife habitat, and recreation use attributes of aspen forests.

The aspen forests of the Bear River Range were analyzed and mapped using data recorded on July 2, 1979 by the Landsat III satellite; study efforts yielded sixty-seven light signatures for the study area, of which three groups were identified as aspen and mapped at a scale of 1:24,000. Analysis and verification of the three groups were accomplished by random location of twenty-six field study plots within the Landsat-defined aspen areas. All study plots are included within the Cache portion of the Wasatch-Cache National Forest. The following selected site characteristics were recorded for each study plot: a list of understory species present; average percent cover and density for understory species; aspen canopy cover estimates and stem measurements; and general site topographic characteristics. The study plot data were then analyzed with respect to corresponding Landsat spectral signatures.

Field studies showed that all twenty-six study plots are associated with one of the three aspen groups. Further study efforts concentrated on characterizing the differences between the site characteristics of plots falling into each of the three aspen groups. Mean values for general understory, overstory, and topographic features for each aspen group have been prepared and statistically significant differences between group attributes are noted. Such analyses provide an initial basis for explaining the correlation between plot characteristics and Landsat signatures. Aspen group differences appear to be associated most strongly with tree canopy, slope, and site moisture attributes.

An analysis was also made to evaluate whether light signatures for aspen are correlated with an understory index to aspen timber site quality, which was developed in a previous study. The results show a statistically significant relationship between Landsat-derived site quality classes and such understory species index, thus producing a spatially referenced index to aspen timber site quality.

INTRODUCTION

Quaking aspen (Populus tremuloides Michx.) is one of the best examples of a multiple-use forest type in the west. The beauty of aspen forests and associated cool environment are held in high esteem by recreationists. Aspen provide an important fire resistant protective watershed cover which is also one of the most efficient water-yielding forest types. The extensive aspen root system serves to effectively bind hillside soils and a typically abundant understory allows great protection against erosion (Sampson, 1919). Aspen has always been important as big game and non-game habitat and, since the coming of man, has become important for summer forage and shade for livestock. Sampson (1919) stated that "as range land, the aspen type is much more valuable than either the spruce-fir just above it or the oak-brush type just below it."

Mule deer are found on all, and elk on many, aspen ranges; aspen is one of the ten species that contribute most to the summer deer diet (Smith, et. al., 1972). Elk especially prefer the aspen sites for summer forage, and aspen stands are often used by elk as calving habitat.

Advances in wood technology have brought the species into recent prominence as a timber tree which is useful primarily for manufacturing of pulp and paper. The most important use of aspen in the Cache National Forest (hereinafter "Cache N.F.") is for firewood. The general view that sizeable areas of Utah aspen forests are rapidly being replaced by conifers makes investigation of this valuable species especially important.

There has been particular interest focused on aspen resources in the Cache N.F. because of a variety of management problems facing the north-central part of the state. For example, population growth along the Wasatch

Front has resulted in increased pressure by recreationists. Also, aspen alpine and subalpine environments continue to be influenced by the activities of man: e.g., domestic grazing, wildfire and fire-suppression activities, and timber harvesting.

Since the launch in July 1972, the NASA series of Landsat satellites have provided a valuable means of analyzing and mapping earth resources. Landsat data are derived from a satellite which, while orbiting the earth at an altitude of 570 miles in a near polar pattern, collects radiance values in four spectral bands of light on the electromagnetic spectrum via a multi-spectral scanner (MSS). The bands sensed by the MSS are numbered four, five, six, and seven, which correspond to electromagnetic wavelengths for visible green, visible red, and two near infrared light bands, respectively. The data are available in the form of computer compatible tapes (CCT) that have the radiance values for all picture elements (pixels) in all four bands. Each pixel represents a piece of the earth's surface with approximately 80m by 80m dimensions. The data may then be processed using a variety of computer programs which have been developed. These programs combine similar radiance value curves of all four bands for the pixels into "light signatures". Each signature is a class that represents light radiance values for different types of ground cover. Each pixel is then classified according to which light signature it best matches, and digitally classified maps are then field checked to determine map accuracy. Thus, Landsat data provides a unique means of analyzing environmental features which is often cost-effective where a high degree of resolution is not required for management purposes.

The study objective has been to provide an analysis and inventory of aspen habitat, using Landsat digital data in the Bear River Range, Utah. The

methods used have been geared to culminate in final map products which will be used by foresters on federal and state lands in evaluating the nature and extent of aspen resources. Forest information regarding aspen understory composition and productivity, and timber site quality is needed for formulating aspen forest management plans.

Since the Landsat sensor receives light reflected from forest overstory and understory characteristics, a major goal of this study became that of correlating field observations of different aspen stands with light signatures produced from Landsat data. In addition, it seems reasonable to expect that light signatures should have some correlation with a synthetic aspen timber site quality index developed by Warner and Harper (1972). Such index was successfully used to predict site quality for aspen timber growth from understory species composition with the following advantages:

> "Prediction based on understory vegetation would require only field samples of relative simplicity. Furthermore, predictions based on understory species can reveal much about quality and quantity of forage in the forest understory. Predictions based on understory parameters could thus have value for multiple use decisions." Warner and Harper (1972, p. 22, 23).

Thus, it is the intent of this study to explore the possibilities of expanding the management economies which accompany the identification of resource indexes by correlating Landsat data with the Warner and Harper (1972) understory index; the result would be a spatially referenced index to aspen timber site quality.

LITERATURE REVIEW

Despite the extensive literature on aspen ecology in general, there is limited information available on aspen in Utah, and even less for the Cache N.F.

Baker (1925) stands out as a paper that covers aspen ecology in the west. Other studies have considered individual aspects of aspen ecology: A popularized account of aspen ecology in the west was published by Cottam (1963), and a paper by Alder (1969) studied the age structure of aspen forests in Utah.

Several investigators such as Allan (1962), Ellison and Houston (1958), and Houston (1952), have provided data on understory of aspen in Utah. The most extensive work has been done in the area of grazing and its effects on aspen. Such studies include Baker (1918), Sampson (1919), Houston (1952), Alder (1969). Several studies have included study plots in the Cache N.F., such as Coles (1965), Hutchins (1965), Lucas (1969), and Smith, et al. (1972).

The debate on aspen as a seral versus stable forest type is presented in papers such as Baker (1918, 1925), Fetherolf (1917), Daubenmire (1943), and Reed (1952), and others. The fact that many aspen stands are being invaded by conifers is well established. (See Bartos, 1973; Mueggler, 1976).

A number of investigators have considered individual environmental factors affecting the growth and development of aspen. Jones (1967a) studied the effects of climate, topography, and edaphic characteristics on height growth of aspen in Colorado. In Jones (1967b), an aspen site index was developed based on height and tree age. Gifford (1967) evaluated the effects of different growth media, temperature, and light intensities on aspen root and stem growth.

Although few investigators have successfully used understory species as indicators of site quality for tree growth, Rowe (1956) and Daubenmire (1961) have reported encouraging results. One study that stands out as having particular applicability to aspen management was performed by Warner and Harper (1972). That paper dealt with the development of an aspen timber site quality index in Utah based upon the presence of understory plant species. The data in their paper has provided a substantial quantitative base for structuring the present study.

There is a great deal of literature available on remote sensing and the use of Landsat in providing tools for natural resource managers. For the purposes of this study, other studies in the remote sensing literature regarding forest resources proved to be of limited utility since they either did not include aspen or else the analysis and mapping of aspen did not occur with the detail needed here (e.g., Meyers, et. al., 1977).

STUDY APPROACH

The analysis and mapping performed in this study was accomplished at the facilities of the Center for Remote Sensing and Cartography, using digital data obtained from NASA's Landsat III satellite. The data necessary for the study, a computer compatible tape (CCT) recorded July 2, 1979, was already available at the Center. For data processing, the Center provided access to computer software routine, "ELAS" developed by NASA's Earth Resources Laboratory in Missouri, which was operational on the University of Utah Research Institute's PRIME computer.

A brief explanation of the nature of the data contained on CCT's follows. Each Landsat scene represents a high matrix of individual cells called picture elements or "pixels", for which radiance values are recorded. Each scene contains over ten million pixels, which are approximately 80 meters square (ca. 1.0 acre). The satellite's multispectral scanner (MSS) records light reflectance values for the combined land cover or terrain features contained within each pixel. Reflectance values for four light spectral bands, two in the visable and two in the non-visable near infrared portions of the electromagnetic spectrum, are electronically relayed to earth receiving stations. The wavelengths corresponding to each band are as follows:

Band 4 (green light)	500-600 nanometers (10^{-9}m);
Band 5 (red light)	600-700 nanometers;
Band 6 (near infrared)	700-800 nanometers;
Band 7 (near infrared)	800-1100 nanometers

The digital processing of Landsat data is performed to use MSS values for each pixel in classifying pixels of similar spectral characteristics

into groups or classes, which can then be correlated with field data or "ground truth". The primary rationale for performing digital processing of MSS data has been stated by Hutchinson (1982), as follows:

> "The argument made for digital multispectral classification is that, when considering the spectrum as a whole, different objects have different patterns of reflection and emission. Further, it is assumed that these spectral patterns are sufficiently unique to make objects consistently distinguishable from one another using statistical classification techniques."

Although Landsat is a relatively inexpensive means of analyzing and inventorying large areas of vegetation resources, variability of objects within a single multispectral classification may be quite high (Todd, et al., 1980). For this reason, efforts to increase resolution, and, more importantly, efforts to use ancillary data (e.g., digital topographic data) to improve classifications are being performed. (See Tom and Miller, 1980.) This study, however, explores the utility of analyzing only spectral reflectance data to accomplish the objective.

Raw Landsat data must first be reformatted to make it compatible with processing software. Next, the digital data are geographically corrected to remove the effects of earth curvature, spin, etc. (See Stage 1 of Figure 1.) Thereafter, a program called "SEARCH" is utilized to generate statistics which characterize pixel groups having similar spectral features across the four bands. (See Stage 2 of Figure 1.) SEARCH is a routine which is used to provide training statistics for a program called "MAXL63", which classifies individual pixels into groups based upon each pixel's highest statistical probability of belonging to a given group. In SEARCH, each

LANDSAT DIGITAL DATA ANALYSIS: STAGES 1 AND 2

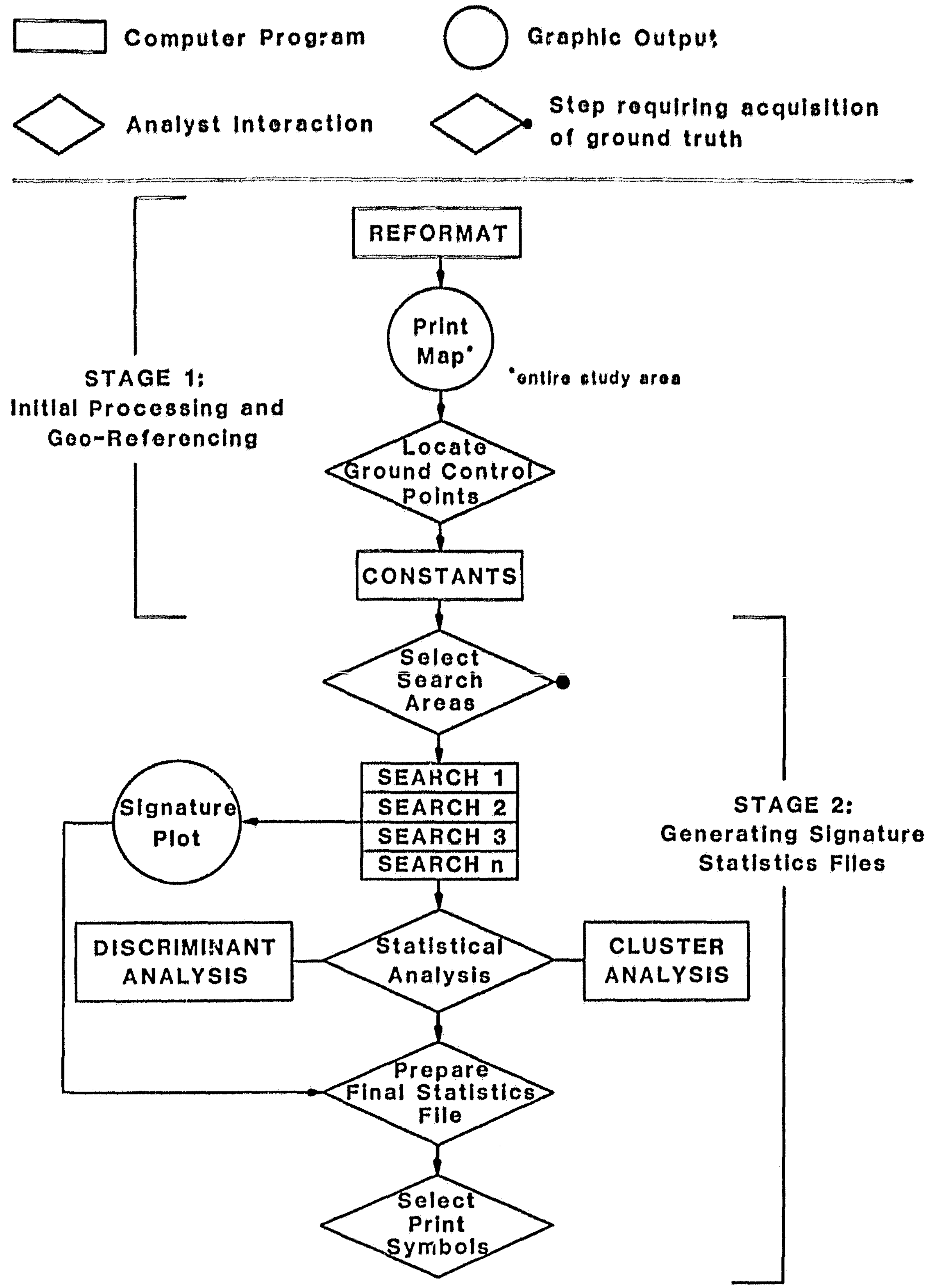


Figure 1. Summary of steps in Landsat digital data analysis: Stages 1 and 2.

contiguous six scan line (Landsat pixel matrix "row") by six element block (pixel matrix "column") is evaluated; if the spectral data within the six by six block is too heterogeneous, the program will switch to the use of a three by three block of pixels. The statistics generated by SEARCH include mean pixel light radiance values for each of the four bands, a covariance matrix, and a priori values. A set of statistics is generated by SEARCH representing various classes of light reflectance patterns found in the study area "searched". The four mean light reflectance values, one for each MSS band, are plotted to form a curve called a "light signature" which characterizes each class. SEARCH thus "trains" MAXL63 to recognize different ground cover patterns as it places individual pixels into classes. A knowledge of the manner in which different land cover features form spectral signatures, combined with the analysis of aerial photography and field checking of digital classifications, allows remote sensing researchers to provide an interpretation of Landsat-derived classes.

In this study, the SEARCH program produced some sixty-seven signatures, of which seven were associated with aspen. The initial correlation of such seven signatures with aspen was accomplished through air photo interpretation of large scale black and white and U-2 plane color infrared photography and two trips to the study area. Further simplification of the classification was accomplished by combining two of the seven aspen signatures into each of two groups and placing the remaining three signatures into a third group. The manner by which classes were combined was based on spectral signature similarity, a discriminant analysis of the signatures, and by generating print maps of selected areas and calibrating print symbols with ground observations. (See Stage 2 in Figure 1, and Stage 3 in Figure 2.)

LANDSAT DIGITAL DATA ANALYSIS: STAGES 3 AND 4

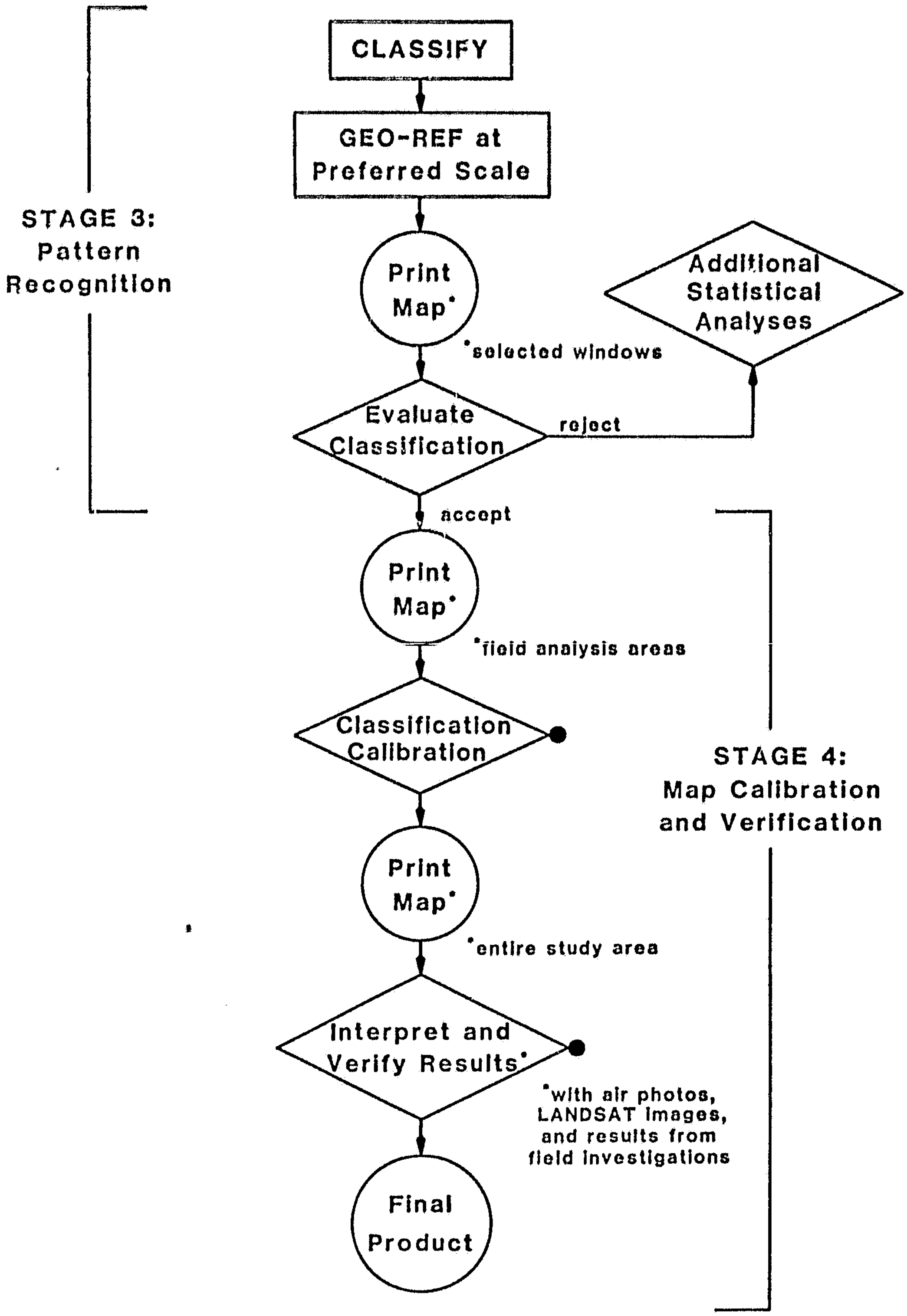


Figure 2. Summary of steps in Landsat digital data analysis: Stages 3 and 4.

To provide the basis for field verification of the aspen signatures generated, a computer print map was produced at a scale of 1:24,000; all seven aspen signatures were assigned the same print character for the map. The Landsat computer print map was then overlayed on U.S.G.S. 7.5 minute topographic maps of the study area. A grid was placed over all areas of homogeneous aspen distribution. Each grid cell was four pixels in size (2x2), and study plots were to be selected as the center of grid cells to accommodate any errors in registration between the Landsat and U.S.G.S. topographic maps. All grid cells were numbered and twenty-six field study plots were picked using a random numbers table.

Vegetation sampling of the study plots occurred in July and August of 1980. Figure 3 shows the locations of the study plots. The field work consisted of locating each study plot in the field from U.S.G.S. maps, and setting up a $400m^2$ plot (20x20m). For understory species density information, five quadrats, with one meter by one meter dimensions, were placed within the plot: one in each corner five meters from either plot side, and one in the plot center. After density data was gathered, a general ocular estimate of percent bare ground and percent cover, by cover class, for individual species occurring in the study plot was made. The individual species cover information was used to obtain plant life form group and total cover estimates. Since cover data was estimated for individual species which often occurred in a multi-layered understory, the sum of total living cover and base ground typically exceeds 100%. A list of all species present in each plot was maintained; the species list for all plants encountered appears in the Appendix.

Several measurements of aspen stand characteristics in each plot were made. Individual tree characteristics were recorded for the four trees

closest to the plot center, with one tree located in each of the plot's quadrants (Cottam and Curtis, 1956; Philips, 1959). For such trees, tree height, diameter at breast height, and distance from the plot center were recorded. Photographs of the canopy were taken at three points along a center plot transect to estimate percent canopy cover. The number of aspen stems per plot was recorded.

The following topography-related site factors were measured on each plot: elevation, aspect, and slope. Slope was determined by the use of a clinometer; aspect was determined with a compass; elevation was obtained from U.S.G.S. topographic maps. The compass reading for aspect was converted to an aspect index where north was assigned a value of 0.0 and south a value of 2.0; east and west had a 1.0 value. An estimate of annual solar radiation received at each plot was made after Lee (1966); such estimates, in kilocalories/cm^2/year, were obtained from tables which present insolation rate as a function of slope and aspect for a given latitude.

Plot understory species presence data were used to apply the understory plant index to aspen timber site quality developed by Warner and Harper (1972) (hereinafter, "Warner/Harper Index").

The twenty-six study plots were then grouped according to one of the three corresponding Landsat aspen group signatures. Analyses of variance were performed to detect significant differences between the three group means for the plot understory, tree, and topographic factors measured and for the Warner/Harper Index.

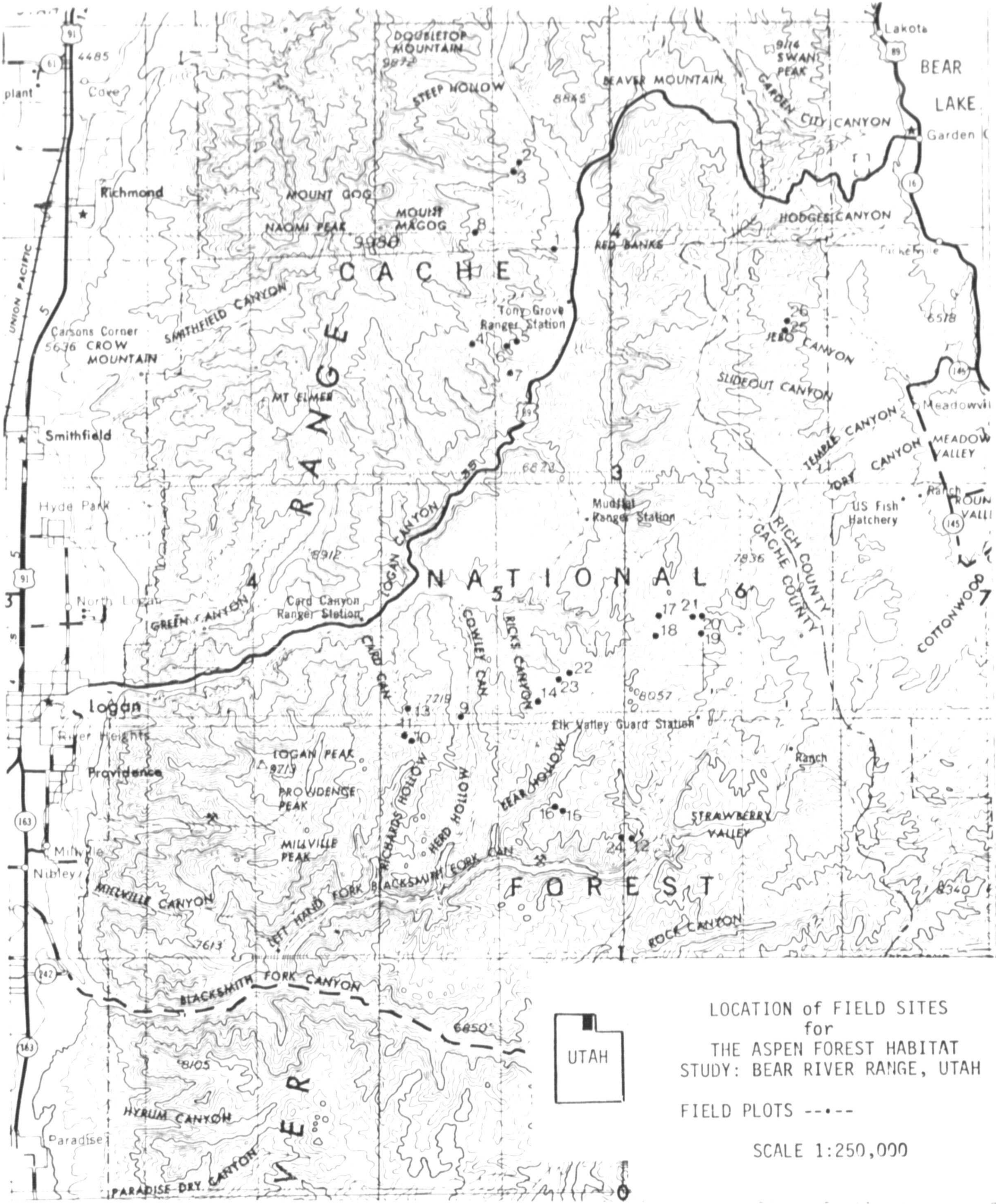


Figure 3. Location of study area and twenty-six field study plots within the Cache National Forest, Utah.

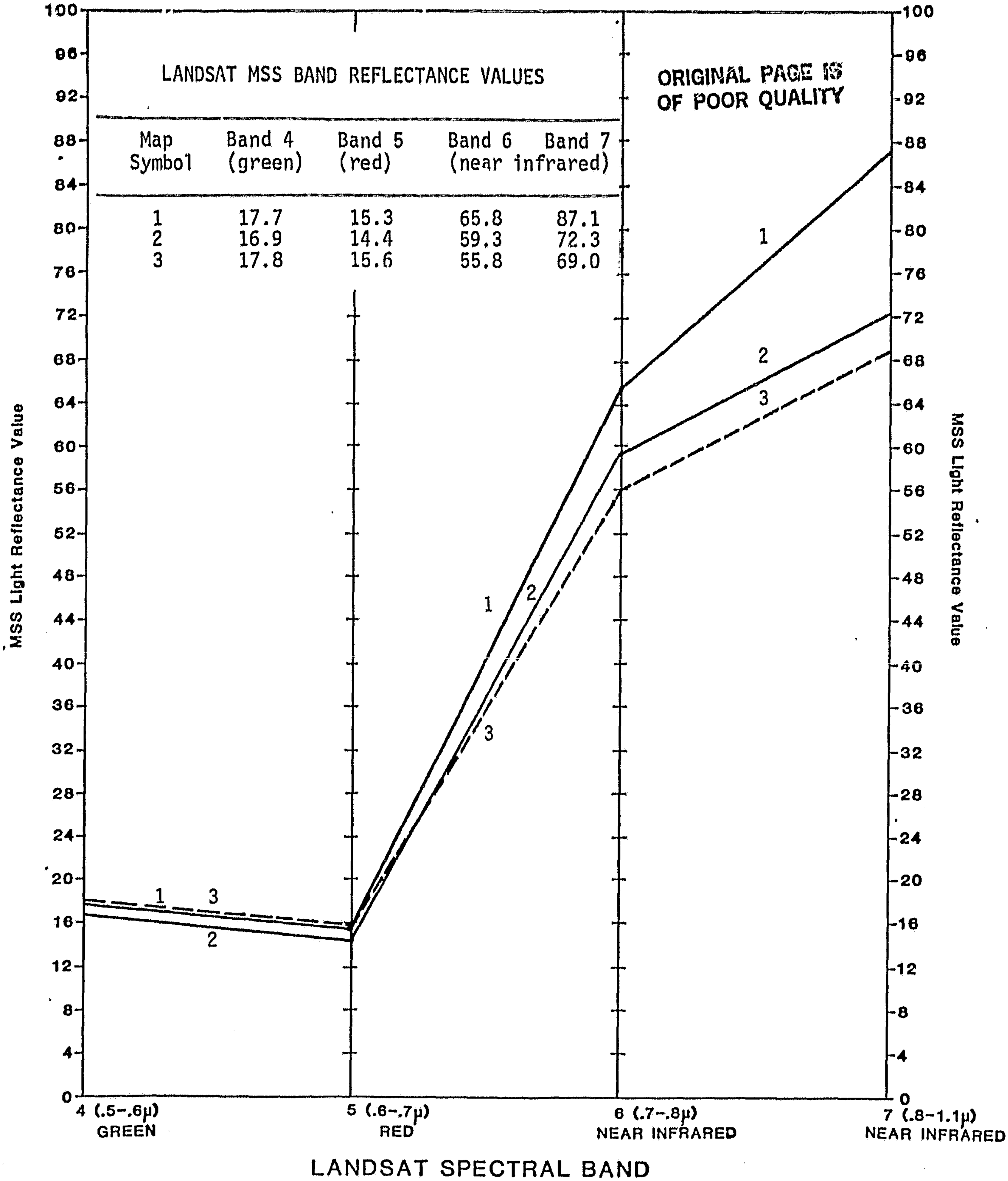
RESULTS AND DISCUSSION

Aspen Classes and Site Characteristics

The light signatures for three aspen groups, from processed digital Landsat MSS data, appear in Figure 4. It may be seen from such figure that aspen group reflects relatively high in the near infrared light bands, but is similar to groups 2 and 3 in the visible bands; the relative response in the infrared bands was the basis for designating the groups 1, 2, and 3. As mentioned above, the spectral signatures are primarily a product of the signature class statistics generated by the program SEARCH. Although the digital processing of Landsat data yields related, but different, signatures for aspen, further analysis of the signatures is possible only by reference to the field "ground truth" data.

The final map products contain the legend presented in Figure 5. Although this study has focused on the signatures representing aspen forests, use of aerial photographs and field observations has allowed a limited interpretation of signatures associated with thin aspen, shrub/aspen, conifer/aspen, and conifer forest types. An example of a portion of the print maps produced is presented in Figure 6.

All of the twenty-six study plots, located in areas which had been classified into one of the spectral signatures believed to be aspen, were found to be within aspen forest habitat. This suggests that there has been a minimal amount of confusion between the aspen forest signatures of Figure 4 and shrub/aspen areas (which have a higher reflectance in the infrared bands), thin aspen, and conifer/aspen mix. However, further field checking of the final print maps will yield information about the integrity of the Landsat classification of aspen. The remainder of this discussion will focus on the relative differences between the three types of aspen habitat which have been mapped.



Map Symbol	Band 4 (green)	Band 5 (red)	Band 6 (near infrared)	Band 7 (near infrared)
1	17.7	15.3	65.8	87.1
2	16.9	14.4	59.3	72.3
3	17.8	15.6	55.8	69.0

Figure 4. Light signature curves based on the aspen group mean values shown in the inset table. The vertical axis represents reflectance values for the three different classes of pixels, as obtained from Landsat MSS data. The four points on the horizontal axis correspond to the spectral bands recorded by Landsat, with associated electromagnetic energy wavelengths in microns (10^{-6}m).

LEGEND

1– Aspen Forest, Medium Quality

2– Aspen Forest, High Quality

3– Aspen Forest, Low Quality

+ Thin Aspen Forest

X Conifer / Aspen Mix

: Shrub / Aspen Mix

* Conifer Forest

Figure 5. Aspen forest habitat map legend.

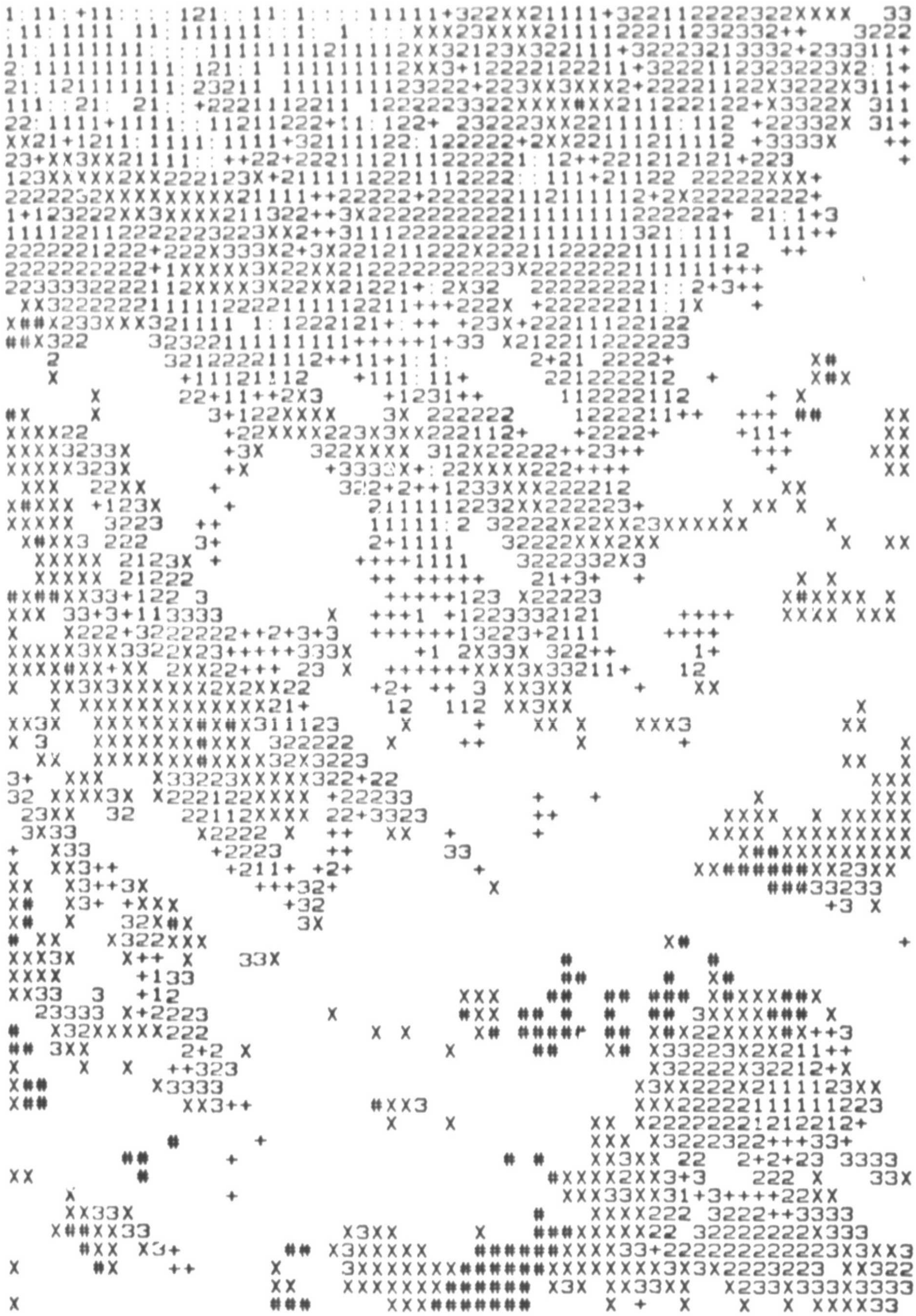


Figure 6. Portion of the Temple Peak quadrangle aspen forest habitat overlay.

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The mean values for the measured site characteristics, with the exception of individual plant species cover and density data, are presented in Table 1. The table also shows the standard deviations and minima and maxima for the site factor means in each of the three groups. Note that the mean values in Table 1 reflect the average of five plots for group 1, fifteen plots for group 2, and six plots for group 3.

Differences between the aspen signature groups have also been evaluated for the prevalent plant species. Species were considered prevalent if they occurred on more than five of the twenty-six study plots. The prevalent species that were statistically evaluated appear in Table 2.

Table 3 presents the relatively significant results of the analyses of variance for all site characteristics. The site characteristics which do not appear in Table 3 did not meet the criterion of having a group F statistic that is significant at the 0.2 level or lower. The site characteristics in the upper portion of Table 3 suggest that aspen group 2 represents the highest quality of aspen habitat: the trees tend to be taller, canopy cover is moderate, and the understory index of site quality is highest.

Since the mean differences in the Warner/Harper understory index of site quality is highly significant for the group analysis of variance, and quite significant for all paired mean comparisons as well, the index will be described in detail. The Warner/Harper Index was developed to correlate aspen understory species presence with the aspen timber site quality curves of Jones (1967b). Such index curves were derived from tree height over age at breast-height data. According to Warner and Harper (1972, p. 18, 19), indicator species that were "significantly associated with stands of high or low site quality, average quadrant frequency of understory species of the top 16 stands on the site-quality gradient based on Jones' index was tested

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Table 1. Means, standard deviations, and minimum and maximum values for plot site variables and the Warner/Harper Index, grouped according to aspen Landsat light signatures. Number of plots in each group are shown in parentheses.

	Aspen Signature Group 1 (n=5)				Aspen Signature Group 2 (n=15)				Aspen Signature Group 3 (n=6)			
	Mean	Std.Dev.	Min.	Max.	Mean	Std.Dev.	Min.	Max.	Mean	Std.Dev.	Min.	Max.
TREE CHARACTERISTICS												
Average Tree Height (m) 1/	12	3.6	6.4	16	15	4.4	6.4	22	11	3.4	5.7	15
Diameter at Breast Height (cm) 1/	19	7.0	9.5	26	21	4.9	8.5	28	18	4.9	11	24
Number of Trees / 400m² Plot	42	23	14	75	44	21	23	91	52	17	26	77
Percent Canopy Cover	42	20	23	71	49	13	18	70	60	13	47	77
Avg. Distance from Plot Center (m) 1/	3.3	0.6	2.5	4.0	2.9	1.2	1.8	6.1	2.8	0.8	2.2	4.3
TOPOGRAPHY-RELATED CHARACTERISTICS												
Plot Elevation (m)	2247	106	2085	2329	2207	69	2121	2329	2244	150	2048	2423
Aspect Index 6/	0.95	0.76	0.25	1.75	1.11	0.61	0.25	2.00	0.76	0.57	0.25	1.50
Slope (degrees)	7.6	3.6	4.0	12.0	15	8.2	4.0	29.0	10	6.4	3.0	20.0
Insolation Rate (kilo cal./cm²/year)	244	26	212	279	232	35	163	293	241	27	204	273
UNDERSTORY CHARACTERISTICS 2/												
Shrub Density 3/	1.6	1.1	0.4	2.8	2.4	2.2	0.0	6.8	5.0	7.1	0.0	19
Tall Perennial Forb Density	51	21	34	86	47	22	20	112	36	14	23	54
Short Perennial Forb Density	13	9.2	5	26	12	8.7	4	37	17	9.4	5	26
Grass or Sedge Density	33	16	19	60	27	14	5.6	50	34	19	19	70
Annual Forb Density	81	95	2.4	244	57	66	3.4	276	75	91	28	259
Bare Ground (%)	64	8.2	50	70	56	16	19	79	61	14	38	75
Total Plant Cover (%)	49	18	24	72	60	20	35	100	64	21	45	92
Shrub Cover (%)	16	16	0.0	42	13	14	1.5	44	15	20	0.0	53
Tall Perennial Forb Cover (%) 4/	15	4.4	9.0	21	26	20	9.0	84	25	15	14	54
Short Perennial Forb Cover (%) 4/	4.5	2.1	3.0	7.5	5.5	2.2	3.0	10.5	6.3	2.6	3.0	9.0
Grass or Sedge Cover (%)	3.6	1.3	3.0	6.0	5.2	4.5	1.5	17	5.0	2.0	3.0	7.5
Annual Forb Cover (%)	8.4	5.7	3.0	17	11	4.4	4.5	23	12	2.0	11	15
UNDERSTORY SITE QUALITY INDEX												
Warner/Harper Index 5/	5.1	0.6	4.6	6.0	5.8	0.7	4.6	7.7	4.5	0.9	3.3	5.6

1/ Numbers represent an average of four trees: each tree being the closest to plot center, with one tree chosen from each plot quadrant.

2/ Based on ocular estimates of five 1.0 m² quadrants.

3/ Plant life form density represents the average number of stems for fire 1.0 m² quadrants per plot.

4/ Tall Perennial Forbs are greater than 30 cm in height at maturity; Short Perennial Forbs are less than or equal to 30 cm.

5/ Understory indicator species index to aspen timber site quality (i.e., height-age-site quality curves of Jones, 1967b) as defined by Warner and Harper (1972), and plot species characteristics.

6/ Compass bearing (degrees) were converted to the Aspect Index, where north or 0° = 0.0; south or 180° = 2.0; and east or 90° and west or 270° = 1.0.

Table 2. Prevalent species for which statistical analyses were conducted.

Life Form	Scientific Name
Tree	Populus tremuloides
Shrub	Prunus virginiana
	Symphoricarpos oreophilus
Tall Perennial Forb ($>$ 30 cm)	Achillea millefolium
	Agastache urticifolia
	Erigeron speciosus
	Hackelia micrantha
	Lathyrus lanszwertii
	Lupinus sericeus
	Osmorhiza occidentalis
	Rudbeckia occidentalis
	Senecio serra
	Thalictrum fendleri
	Valeriana occidentalis
Short Perennial Forb ($\leq$ 30 cm)	Hydrophyllum capitatum
	Phacelia hastata
	Stellaria jamesiana
	Viola nuttallii
Grass or Sedge	Bromus carinatus
	Carex hoodii
Annual Forb	Collomia linearis
	Chenopodium fremontii
	Descurainia pinnata
	Galium aparine
	Nemophila breviflora
	Polygonum douglasii

Table 3. Summary of statistical analysis of site characteristics. The table shows results of analyses of variance, comparing the means for the three groups. Only results which yielded less than a 0.2 probability of Type I error are shown. Site characteristic means and the significance level (t-test) of paired comparisons are also shown.

Site Characteristic	Group F	Significance Level	Site Characteristic Means			Significance Level of Paired Mean Comparisons		
			1	2	3	1 vs. 2	1 vs. 3	2 vs. 3
Average Tree Height	1.733	.199	11.9	14.5	11.3	.222	.802	.110
Percent Canopy Cover	2.163	.138	42	49	60	.354	.054	.139
Percent Slope	2.23	.130	7.6	14.9	10.3	.063	.538	.206
Warner/Harper Index	7.058	.004	5.14	5.79	4.45	.106	.145	.001
Species Cover (%)								
Thalictrum fendleri	2.396	.114	2.4	1.7	1.3	.134	.040	.296
Achillea millefolium	3.455	.049	0.6	1.5	1.8	.033	.021	.507
Carex hoodii	1.769	.193	1.5	0.7	1.0	.075	.331	.463
Rudbeckia occidentalis	2.379	.115	1.8	1.2	4.0	.667	.186	.040
Hackelia micrantha	2.343	.119	0.6	0.7	1.5	.816	.084	.056
Valeriana occidentalis	3.076	.066	0.0	0.9	0.3	.038	.608	.103
Collomia linearis	4.333	.025	0.6	1.3	1.5	.019	.011	.447
Polygonum douglasii	3.293	.055	0.6	0.7	1.5	.783	.043	.026
Galium aparine	2.468	.107	0.0	0.8	0.5	.038	.253	.387
Species Density								
Lathyrus lanszwertii	1.756	.195	14.0	17.6	8.9	.475	.397	.076
Senecio serra	1.816	.185	2.6	1.9	0.5	.473	.082	.147
Thalictrum fendleri	6.124	.007	22.5	5.5	2.4	.004	.004	.537
Achillea millefolium	3.841	.036	1.6	2.3	7.0	.735	.029	.018
Carex hoodii	4.106	.030	7.9	0.9	2.7	.009	.082	.441
Hydrophyllum capitatum	2.089	.147	2.8	0.8	0.8	.060	.111	.972
Hackelia micrantha	7.256	.004	0.3	0.6	2.8	.611	.004	.002
Collomia linearis	2.906	.075	0.7	4.5	8.3	.175	.025	.143
Polygonum douglasii	3.297	.055	2.5	0.3	3.0	.094	.746	.032

against the average frequency of the same species in the last 16 stands of that gradient." After all species in the high and low groups were tested, "fifteen were found to be significantly (at the .05 level or better) more or less abundant on the better aspen sites." (Warner and Harper, 1972, p. 19). The site quality indicator species so identified with corresponding indicator value, are presented below; the species found in at least one of the twenty-six field plots of this study are shown with an asterisk.

Species	Warner/Harper Index
Elymus glaucus	8.3
* Lathyrus lanszwertii	8.1
* Viola nuttallii	8.0
Poa curta	7.0
* Mertensia arizonica	6.5
* Floerkea proserpinacoides	5.9
* Thalictrum fendleri	5.4
Heracleum lanatum	5.2
Helenium hoopesii	4.8
Aconitum columbianum	4.6
Gayophytum ramosissimum	2.6
* Symphoricarpos oreophilus	2.6
* Aster englemannii	2.3
Pachistima myrsinites	1.9
* Polygonum douglasii	1.0

The Warner/Harper Index is determined by application of the following formula: $\text{site quality index} = \dfrac{\Sigma \text{ index values for indicators present}}{\Sigma \text{ indicator species present}}$

By applying species presence data for each plot with the index values shown above, individual plot Warner/Harper Index values were calculated. Warner and Harper (1972) noted that the correlation coefficient between the Jones (1967b) natural site index and the Warner Harper Index was +0.64 (r^2=0.41), which is significant at the .01 level.

The principal advantage of a device such as the Warner/Harper Index is that it uses the "bio-synthesizing" attributes of plant species to provide

management information with a minimum of effort. Each plant species may be expected to be found were the variety of environmental factors, including nutrition, light, moisture, and temperature, permit the plant to be successful. The presence and relative abundance of plant species in an area should indicate information about the biotic and abiotic characteristics of a site. By correlating the presence of plants with site quality information, Warner and Harper (1972) provided a simple means of estimating site quality without the necessity of measuring tree heights and ages. Thus, the correlation of Landsat-derived aspen forest groups with the Warner/Harper Index suggests that a combination of site factors are responsible for the spectral differences; Landsat cannot "see" site quality, but apparently is sensitive to the factors which have produced the better aspen habitat.

Slope appears to be one site characteristic which separates the three groups; group 2 has a mean slope of nearly 15 degrees, which is significantly steeper than group 1's slope of nearly 8 degrees. This condition suggests a reason why group 2's reflectance in the infrared bands (see Figure 4) is lower than group 1's response, even though the trees appear to be larger; slope steepness creates greater shadowing, which reduces overall reflectance.

In addition to having the tallest trees, the data also suggest that group 2's trees have the greatest diameter at breast height (dbh). (See Table 1.) Although the group F value precluded dbh from being present in Table 3, the paired t-test between groups 2 and 3 was significant at the 0.167 level.

Although the canopy cover is greatest for group 3, a couple of factors appear to explain why, in spite of this result, the infrared reflectance is lowest for group 3. First, as will be pointed out below, groups 1 and 2 tend

to be moister sites, which would provide a partial explanation. Also, the trees in group 3 are relatively short and shrubs in such sites tend to be tall: both conditions would have biased the canopy cover estimate based on vertical photographs. In addition, higher shrub density, significant only with paired t-tests between group 3 and groups 1 and 2, may have biased the canopy cover estimates in favor of group 3.

The results of the individual species analyses of variance, shown in Table 3, suggests that groups 1 and 2 are relatively moist. Indicators of relatively moist areas, such as (genera noted only) Thalictrum, Senecio, Hydrophyllum, and Lathyrus appear to prefer groups 1 and 2. Conversely, species which indicate greater tolerance for drier sites, such as Achillea, Hackelia, Collomia, and Polygonum, seem to prefer group 3 areas. Warner and Harper (1972) determined Thalictrum and Lathyrus to be indicators of good aspen site quality, which would reflect moisture availability, and Polygonum to be an indicator of poor aspen site quality; the relative abundance of these three species among the aspen groups further supports the inference that site moisture conditions are being reflected through the vegetation and were sensed by Landsat. It is possible to use the indicator value of the species mentioned above to reflect grazing pressure; species indicative of moister sites also indicate reduced grazing pressure. However, there is no grazing information available to further evaluate this possibility.

Digital processing of Landsat MSS data offers the advantage of automatic tabulation of area covered by map symbols. Table 4 presents the area tabulations for the aspen forest habitat groups for the area on each of the U.S.G.S. topographic quadrangles studied. With a total estimated study area of 270,000 acres, the combined aspen habitat for the three groups makes up approximately 15% of the area.

Table 4. Area tabulations for the three aspen forest groups for the regions mapped on each U.S.G.S. quadrangle.

Quadrangle Name	Aspen Forest Area (acres)		
	Group 1	Group 2	Group 3
Naomi Peak	159	323	602
Tony Grove Creek	2,062	2,623	1,946
Garden City (W½)	54	339	910
Mt. Elmer	685	1,030	1,136
Temple Peak	1,703	3,382	2,120
Meadowville (W½)	540	2,099	1,786
Logan Peak	2,166	2,638	1,667
Boulder Mtn.	2,071	4,301	2,820
Red Spur Mtn. (W½)	310	975	1,133
TOTALS	9,750	17,710	14,120

It should be noted that a more extended evaluation of the site characteristics for different aspen habitat groups is not possible because of the limited sample size of field data. The adequacy of the field samples for several site factors has been evaluated with the following formula:

$$\text{Minimum sample needed} = \left(\frac{(t)\ (cv)}{(AE)} \right)^2$$

Where, t = student's t value

CV = coefficient of variation $\left(\frac{\text{standard deviation} \times 100}{\text{sample mean}} \right)$

AE = allowable error (%).

The minimum sample needed was determined to meet the accuracy criteria of obtaining a sample which is within 10% of the true population mean, with a probability level for Type I error of 20%. Using these criteria, a desirable sample for tree characteristics is approximately 20 plots for each group. To obtain an adequate sample for topographic and most understory characteristics, 50 or more samples would be needed. Thus, it is clear that, in performing field studies in connection with Landsat analyses, it is preferable to locate more study sites than to focus on acquiring a large variety of data at each site.

CONCLUSION

Aspen forest habitat maps obtained from Landsat digital MSS data suggest a hierarchy of aspen forest habitat in the Bear River Range. Three aspen groups have been mapped. Aspen habitat group 2 appears to have the largest trees and is correlated with the highest mean value for the Warner/Harper Index of aspen timber site quality. Group 2 appears to have a looser canopy and shorter trees, but seems to occupy relatively mesic sites. Group 3 has a shorter, and perhaps relatively dense, canopy and appears to favor drier sites with relatively low site quality.

The digital print map overlays and area tabulations provide a spatial guide and inventory of the three types of aspen habitat studied. Further field studies are needed to add confidence to the characterization of site attributes presented in this report. Verification of the spatial accuracy and interpretations of map symbols will be provided as the aspen habitat maps are applied by federal and state forest managers.

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APPENDIX

PLANT SPECIES LIST*

Life Form	Scientific Name	Family	Common Name
Tree			
	Populus tremuloides	Salicaceae	quaking aspen
Shrub			
	Acer grandidentatum	Aceraceae	big tooth maple
	Berberis repens	Berberidaceae	Oregon grape
	Symphoricarpos oreophilus	Caprifoliaceae	mountain snowberry
	Amelanchier alnifolia	Rosaceae	saskatoon serviceberry
	Prunus virginiana	Rosaceae	western chokecherry
	Rosa woodsii	Rosaceae	Wood's wild rose
Tall Perennial Forb (> 30 cm)			
	Osmorhiza occidentalis	Apiaceae	western sweet cicely
	Achillea millefolium	Asteraceae	yarrow
	Aster engelmannii	Asteraceae	Englemann aster
	Erigeron speciosus	Asteraceae	showy fleabane
	Hieracium scouleri	Asteraceae	wooly weed
	Rudbekia occidentalis	Asteraceae	coneflower
	Senecio serra	Asteraceae	groundsel
	Cynoglossum officinale	Boraginaceae	houndstongue
	Hackelia micrantha	Boraginaceae	Jessie's tickweed
	Mertensia arizonica	Boraginaceae	Arizona bluebell
	Arabis glabra	Brassicaceae	tower mustard
	Lathyrus lanszwertii	Fabaceae	thickleaf sweetpea
	Lupinus sericeus	Fabaceae	silky lupine
	Agastache urticifolia	Lamiaceae	giant hyssop
	Smilacina stellata	Liliaceae	wild lily-of-the-valley
	Sidalcea oregana	Malvaceae	Oregon checkermallow
	Corallorhiza maculata	Orchidaceae	spotted coralroot
	Polemonium foliosissimum	Polemoniaceae	leafy Jacob's ladder
	Potentilla glandulosa	Rosaceae	gland cinquefoil
	Delphinium occidentale	Ranunculaceae	duncecap larkspur
	Thalictrum fendleri	Ranunculaceae	Fendler meadowrue
	Galium boreale	Rubiaceae	northern bedstraw
	Castilleja miniata	Scrophulariaceae	scarlet paintbrush
	Scrophularia lanceolata	Scrophulariaceae	lance leaf figwort
	Valeriana occidentalis	Valerianaceae	western valerian

APPENDIX: Plant Species List (Continued)

Life Form	Scientific Name	Family	Common Name
Short Perennial Form (≤ 30 cm)			
	Microseris nutans	Asteraceae	nodding scorzonella
	Taraxacum officinale	Asteraceae	common dandelion
	Stellaria jamesiana	Caryophyllaceae	James chickweed
	Stellaria obtusa	Caryophyllaceae	chickweed
	Hydrophyllum capitatum	Hydrophyllaceae	ballhead waterleaf
	Phacelia hastata	Hydrophyllaceae	spearleaf scorpionweed
	Allium bisceptrum	Liliaceae	twincrest onion
	Erythronium grandiflorum	Liliaceae	glacier lily
	Circaea alpina	Onagraceae	enchanter's nightshade
	Mitella stauropetala	Saxifragaceae	small flower miterwort
	Delphinium nuttalianum	Ranunculaceae	larkspur
	Viola nutallii	Violaceae	yellow prairie violet
Grass or Sedge			
	Carex hoodii	Cyperaceae	Hood's sedge
	Bromus carinatus	Poaceae	mountain brome
	Deschampsia elongata	Poaceae	slender hairgrass
	Melica bulbosa	Poaceae	onion grass
	Poa nervosa	Poaceae	Wheeler blue grass
Annual Forb			
	Capsella bursa-pastoris	Brassicaceae	sherpherd's purse
	Descurainia pinnata	Brassicaceae	blue tansy mustard
	Draba stenolaba	Brassicaceae	shiny Draba
	Chenopodium fremontii	Chenopodiaceae	Fremont goosefoot
	Chenopodium hybridum	Chenopodiaceae	maple goosefoot
	Nemophila breviflora	Hydrophyllaceae	woodlove
	Floerkea proserpinacoides	Limnanthaceae	false mermaid
	Collomia linearis	Polemoniaceae	narrowleaf Collomia
	Polygonum douglasii	Polygonaceae	Douglas knotweed
	Galium aparine	Rubiaceae	catchweed bedstraw
	Galium bifolium	Rubiaceae	twinleaf bedstraw
	Collinsia parviflora	Scrophulariaceae	blue-eyed Mary

*Species nomenclature follows Arnow, et al. (1980).